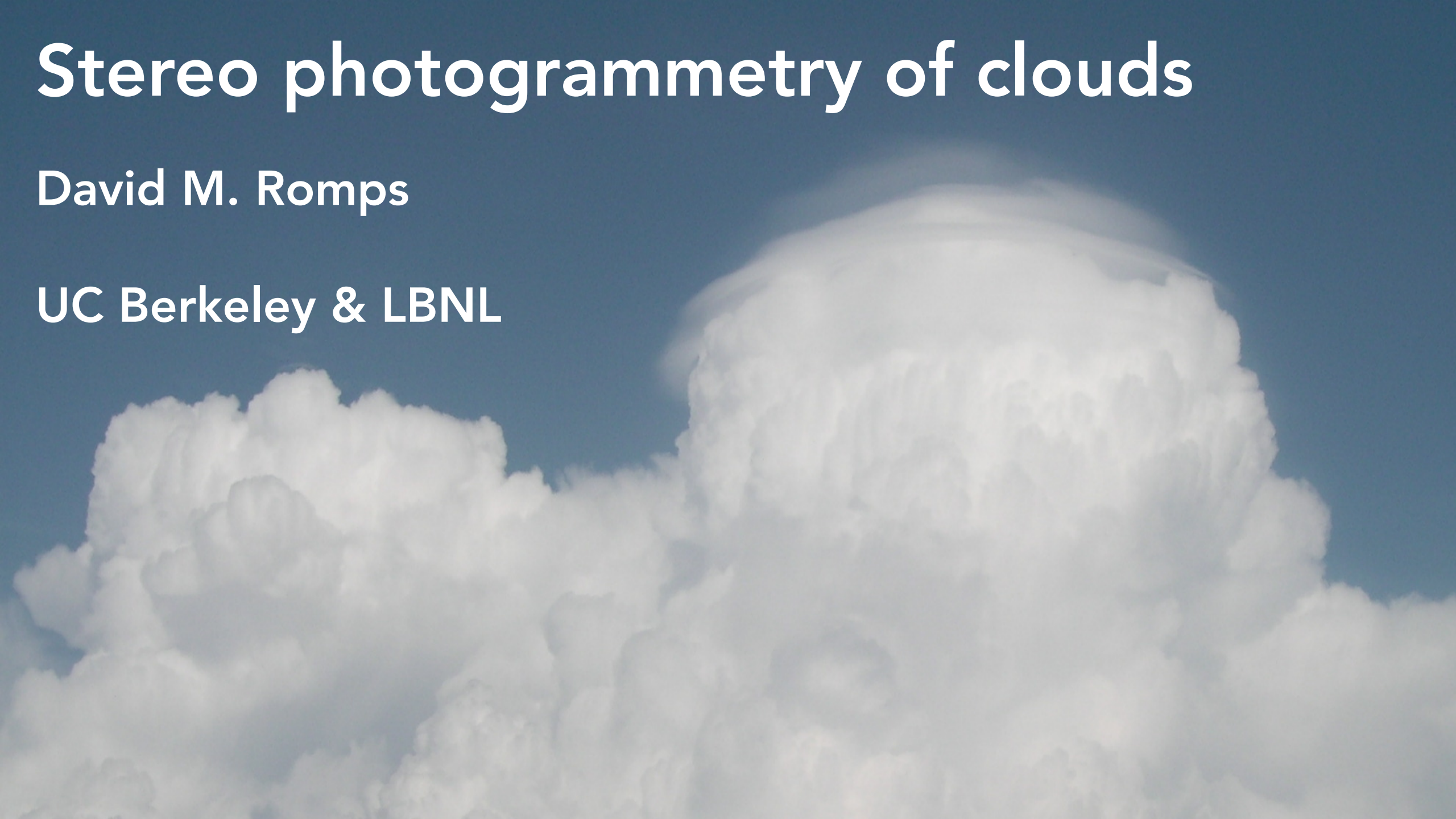
Stereo photogrammetry of clouds

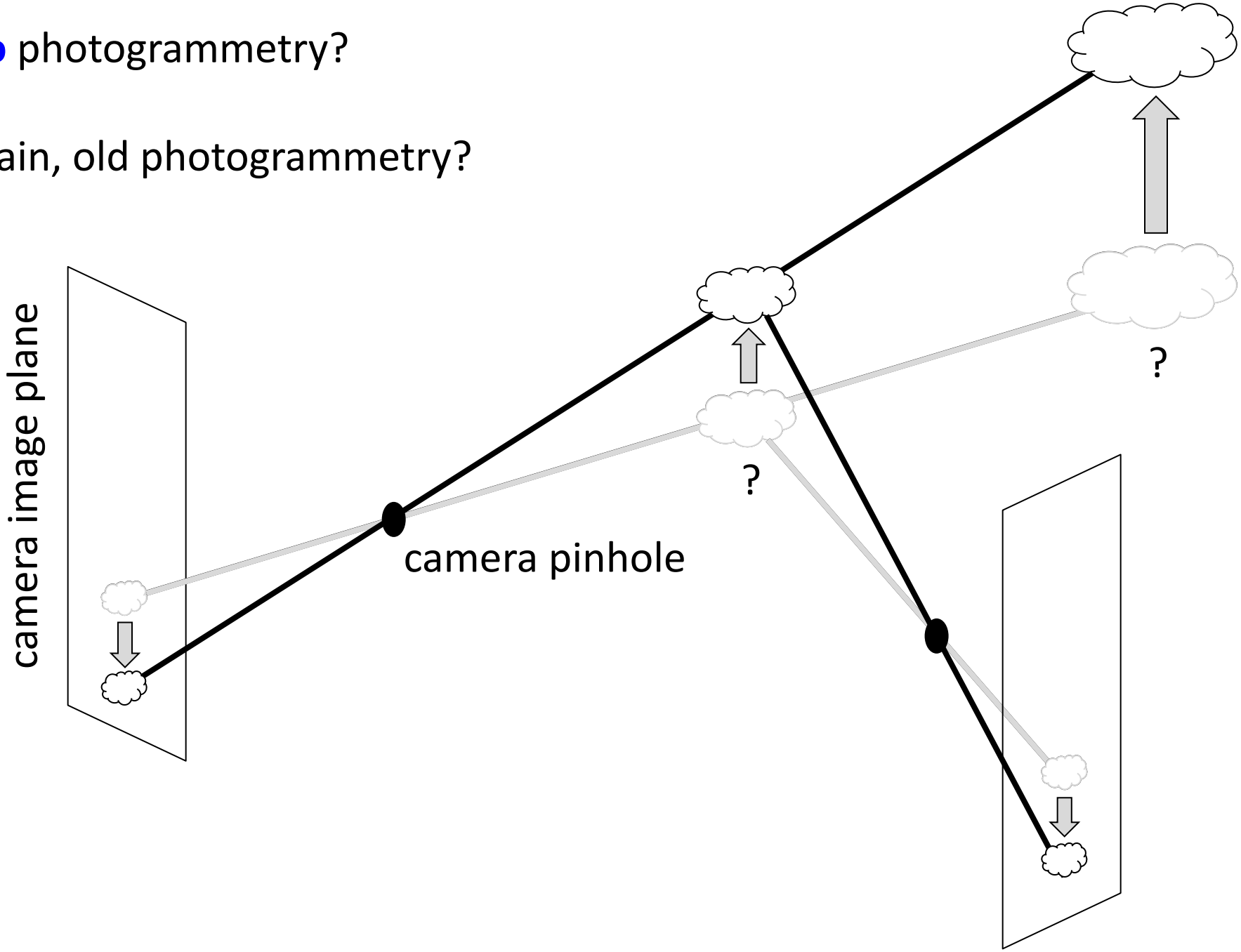
David M. Romps

UC Berkeley & LBNL



Why **stereo** photogrammetry?

Why not plain, old photogrammetry?



Outline

1. Are clouds sticky or slippery?
2. Intro to the latest stereo product: COGS
3. What sets cloud cover?
4. Are clouds thermals or plumes?

Are cloud thermals slippery or sticky?

Are clouds slippery or sticky?

Prologue:
The Introduction

Act I:
Stereo Photogrammetry

Act II:
Large-Eddy Simulations


NetCam SC Sun Aug 25 08:19:00 2013
Exposure: 12


NetCam SC Sun Aug 25 082759 2013
Exposure: 8

What is the dominant balance
in the
vertical momentum equation
for
mature cloud thermals?

$$\frac{dw}{dt} = \text{buoyancy} - \text{drag}$$

dw/dt

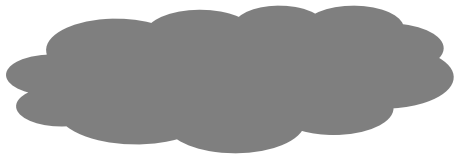
buoyancy

=

drag

dw/dt

buoyancy



=

drag

Argument for “slippery”

Slippery Thermals and the Cumulus Entrainment Paradox*

STEVEN C. SHERWOOD, DANIEL HERNÁNDEZ-DECKERS, AND MAXIME COLIN

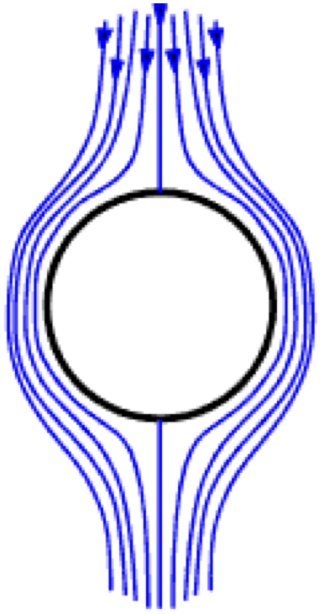
Climate Change Research Centre, and ARC Centre of Excellence for Climate System Science, University of New South Wales, Sydney, New South Wales, Australia

FRANCIS ROBINSON

Department of Geology and Geophysics, Yale University, New Haven, Connecticut

(Manuscript received 1 August 2012, in final form 19 February 2013)

Cloud thermals resemble Hill’s vortex, and Hill’s vortex feels no drag.



Argument for “sticky”

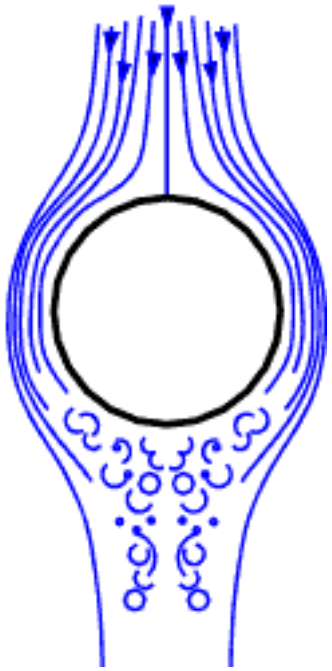
Sticky Thermals: Evidence for a Dominant Balance between Buoyancy and Drag in Cloud Updrafts

DAVID M. ROMPS AND ALEXANDER B. CHARN

Department of Earth and Planetary Science, University of California, Berkeley, and Berkeley Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California

(Manuscript received 9 February 2015, in final form 30 March 2015)

Hill’s vortex is a solution to inviscid flow.
Objects in real fluids feel drag.




NetCam SC Sun Aug 25 082759 2013
Exposure: 8

Are clouds slippery or sticky?

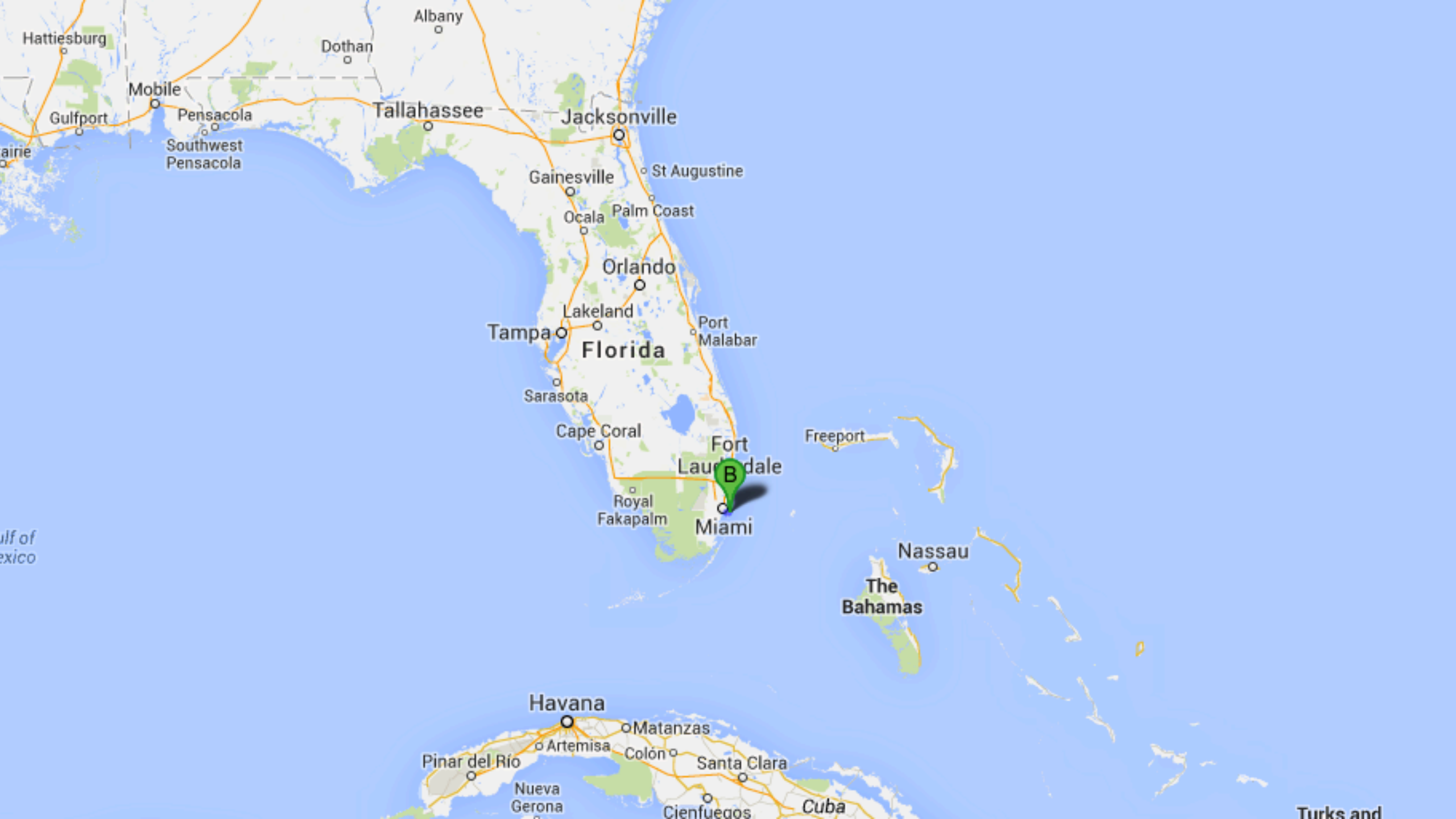
Prologue:
The Introduction

Act I:
Stereo Photogrammetry

Act II:
Large-Eddy Simulations

Rusen Oktem

LBNL & UC Berkeley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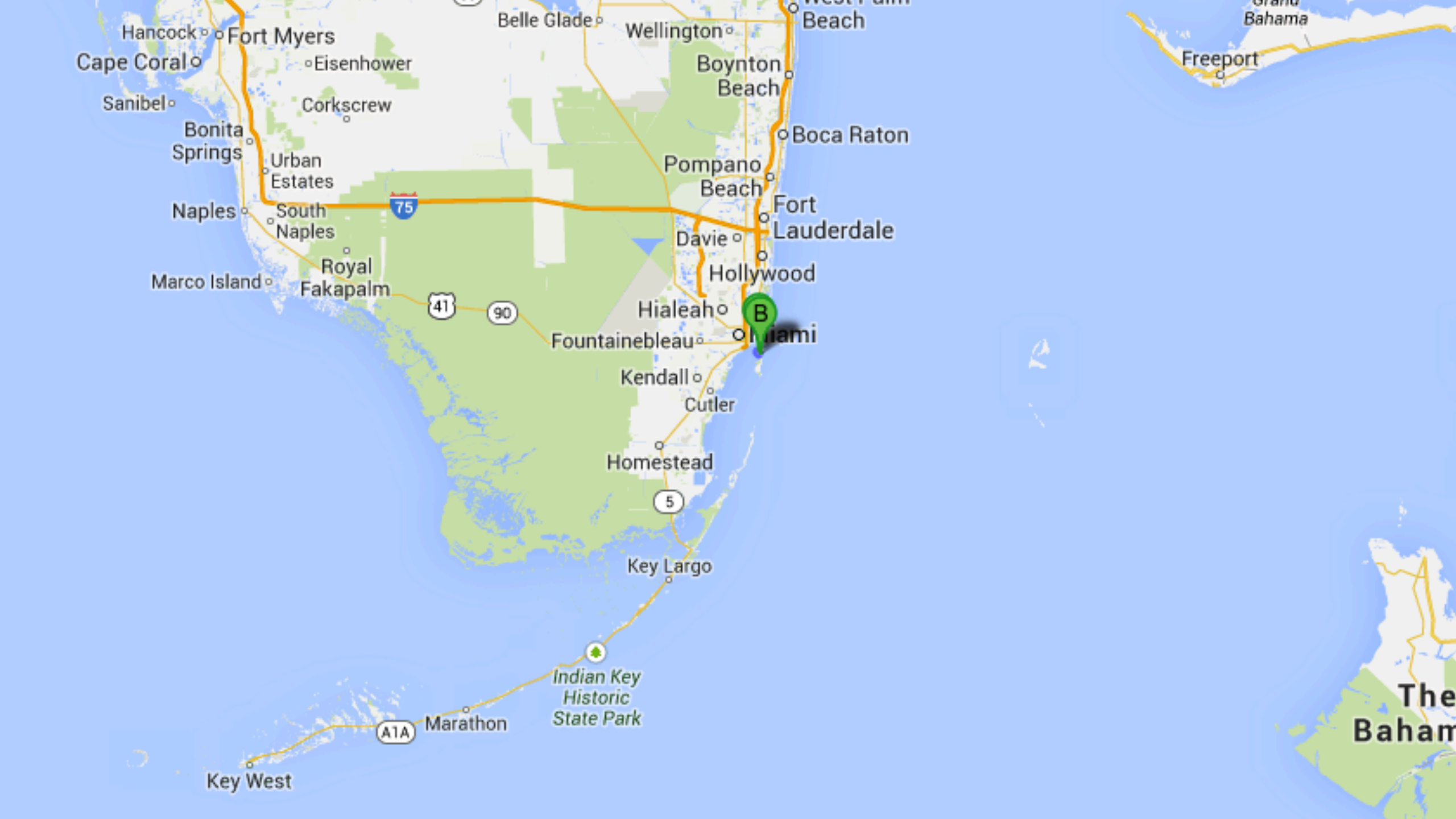
Hattiesburg
Dothan
Mobile
Gulfport
Pensacola
Southwest Pensacola
Tallahassee
Jacksonville
St Augustine
Gainesville
Palm Coast
Ocala
Orlando
Lakeland
Tampa
Port Malabar
Florida
Sarasota
Cape Coral
Freeport
Fort Lauderdale
B
Royal Fakapalm
Miami
Nassau
The Bahamas
Havana
Matanzas
Artemisa
Colón
Pinar del Río
Santa Clara
Nueva Gerona
Cienfuegos
Cuba


Hancock
Fort Myers
Cape Coral
Eisenhower
Sanibel
Corkscrew
Bonita Springs
Urban Estates
Naples
South Naples
Royal Fakapalm
Marco Island
75
41
90
Belle Glade
Wellington
Beach
Boynton Beach
Boca Raton
Pompano Beach
Fort Lauderdale
Davie
Hollywood
Hialeah
B
Fountainebleau
Kendall
Cutler
Homestead
5
Key Largo
Indian Key Historic State Park
A1A
Marathon
Key West
Freeport
Bahama
The
Baham

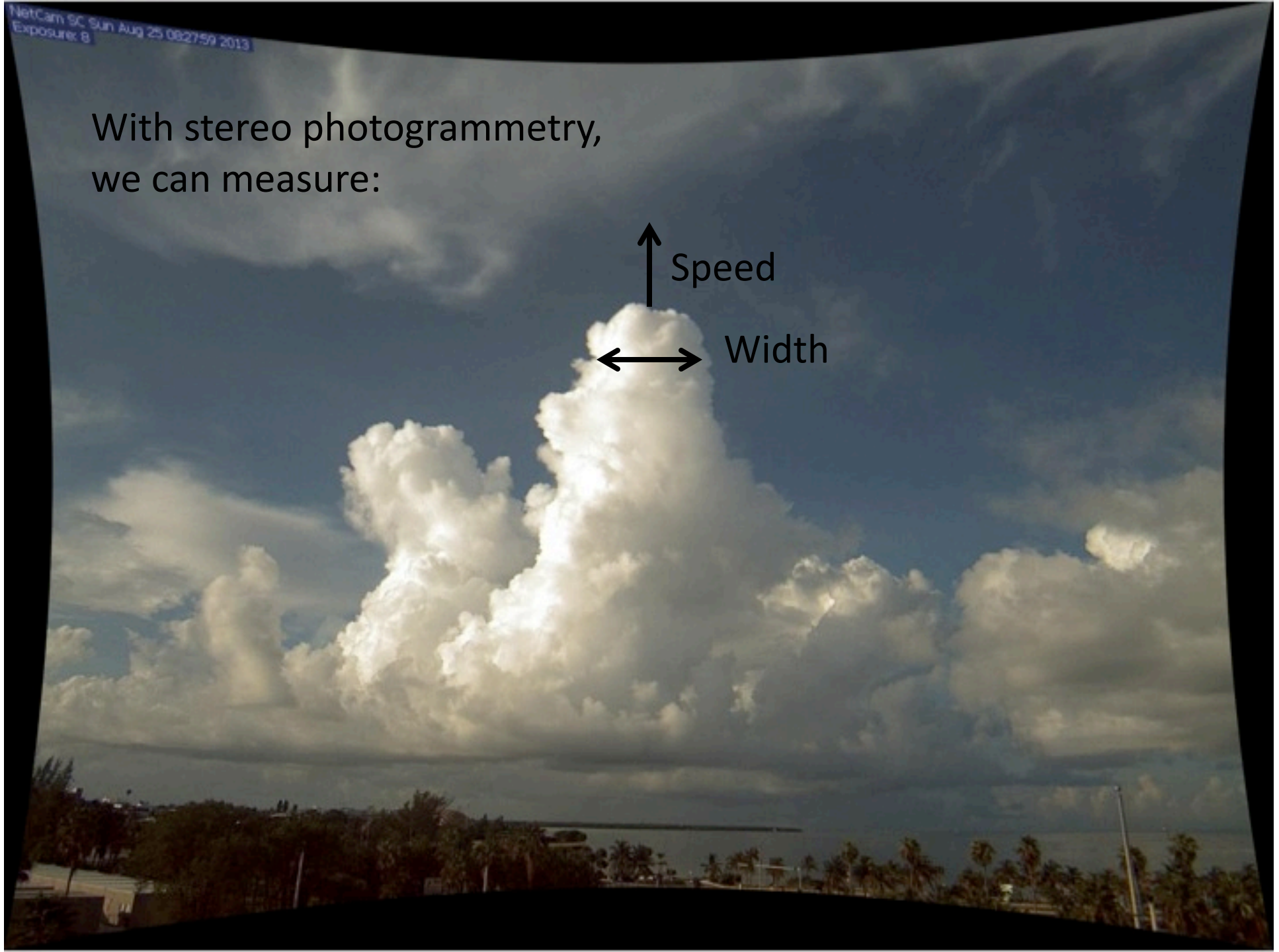

Hialeah
River
North Bay Village
Medley
Gladeview
NE 2nd Ave
Miami Beach
Collins Ave
821
Palmetto Expy
Miami Springs
Brownsville
95
Doral
NW 41st St
Airport Expy
5
195
195
Allapattah
Miami
836
821
Dolphin Expy
836
Fountainebleau
Flagami
Downtown Miami
A1A
South Pointe Park
41
90
90
Tamiami
Westchester
Coral Way
Brickell
A
B
Olympia Heights
Coral Gables
Kendale Lakes
Glenvar Heights
1
Key Biscayne
SW 88th St
N Kendall Dr
94
The Crossings
Kendall
Pinecrest
Montgomery Botanical Center
825
821
Palmetto Estates
Cutler
South Miami Heights
1
Biscayne

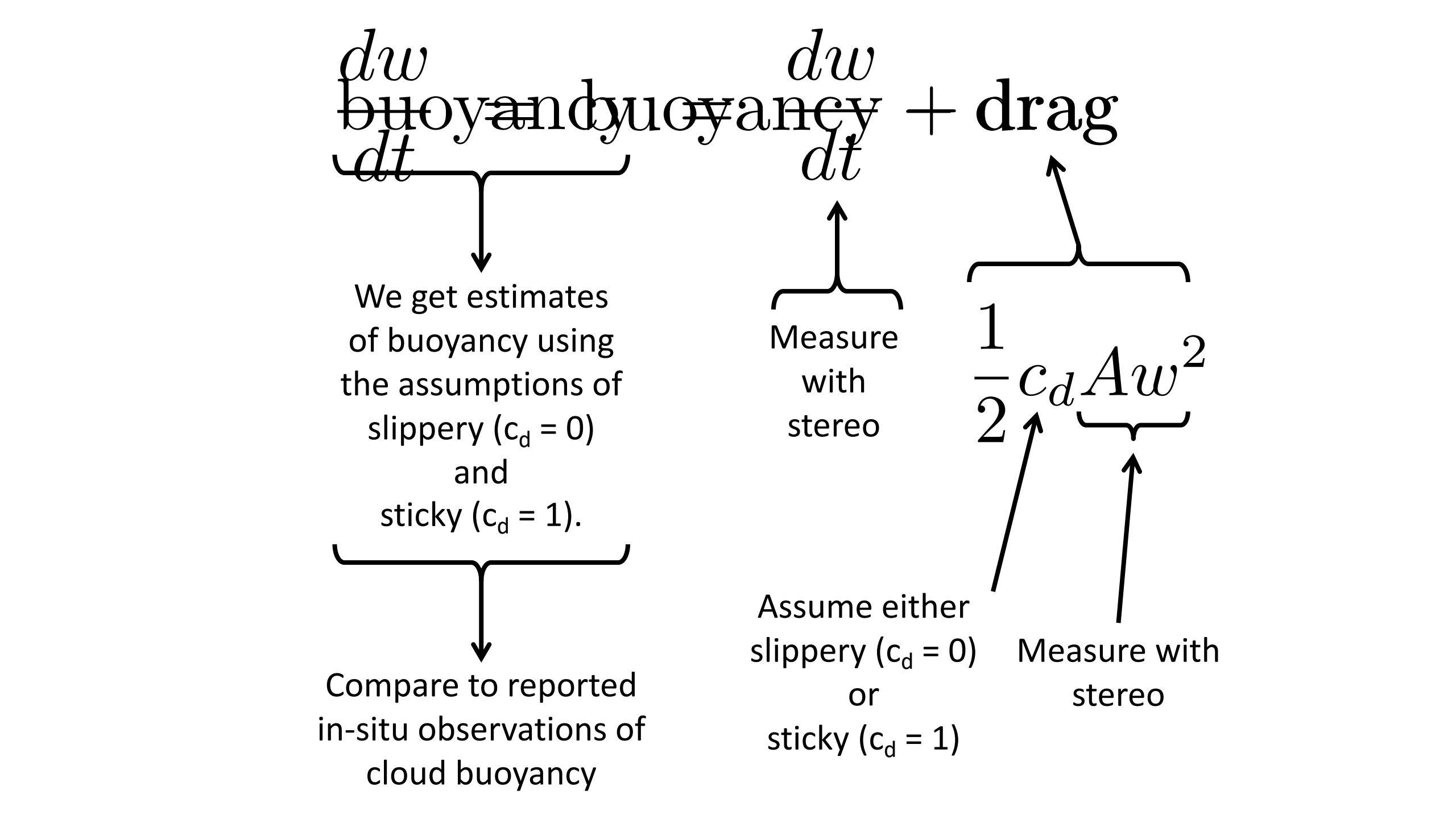

kenbacker Causeway
Rickenbacker Marina
Rickenbacker Causeway
A
MAST Academy
Arthur Lamb Jr Rd
Key Beach Park
Southeast Fisheries
Miami Seaquarium
B
RSMAS
Rosenstiel School of Marine and Atmospheric Science
Top Gun Charters - Miami
Crandon Blvd
913
Crandon Golf Key Biscayne

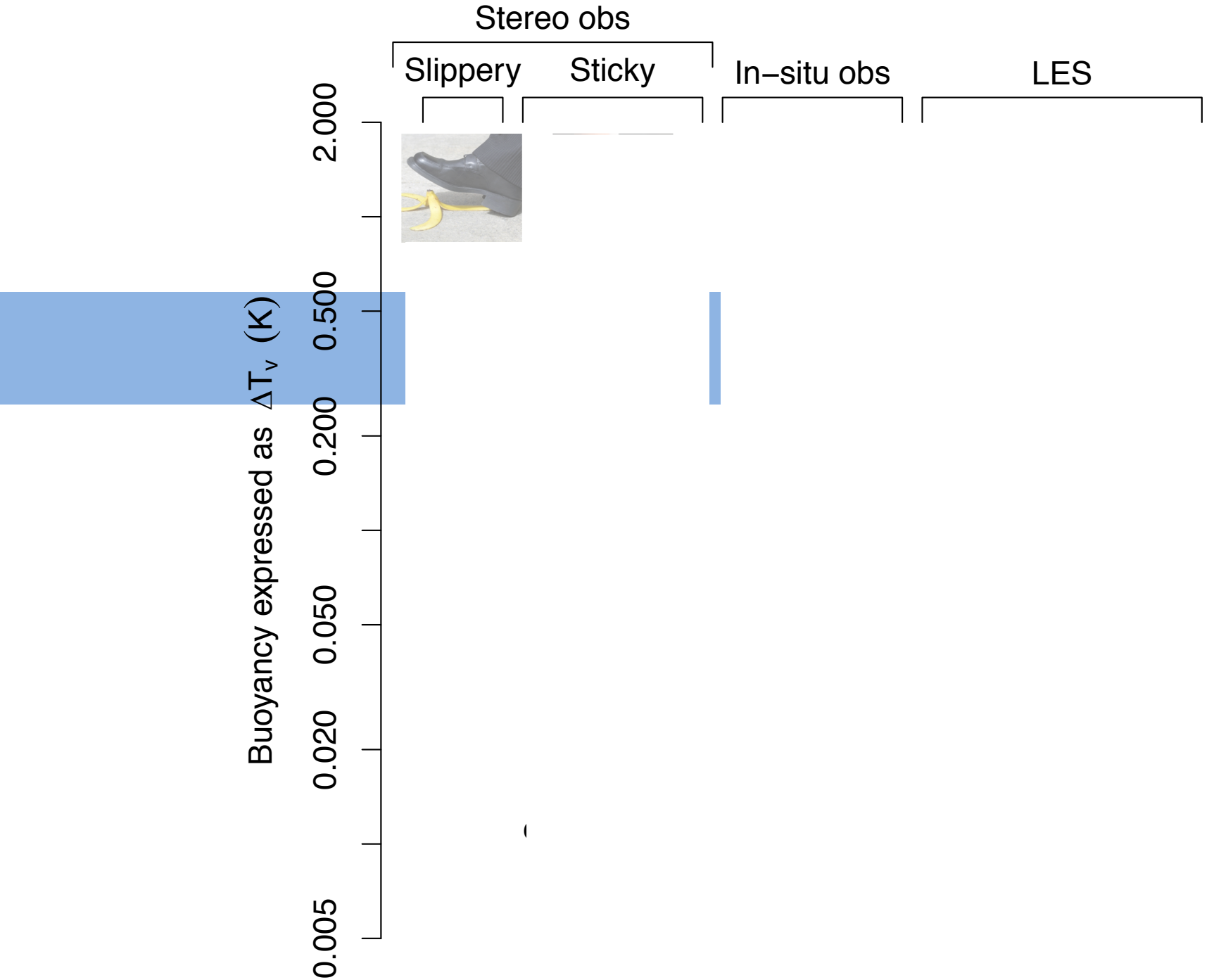

MAST Academy
MAST Academy


MAST Academy


Starlink


NetCam SC Sun Aug 25 082759 2013
Exposure: 8
With stereo photogrammetry,
we can measure:
Speed
Width


$\frac{dw}{dt}$ buoyancy
$\frac{dw}{dt}$ buoyancy + drag
We get estimates of buoyancy using the assumptions of slippery ($c_d = 0$) and sticky ($c_d = 1$).
Compare to reported in-situ observations of cloud buoyancy
Measure with stereo
$\frac{1}{2} c_d A w^2$
Assume either slippery ($c_d = 0$) or sticky ($c_d = 1$)
Measure with stereo



Sticky hypothesis is consistent with obs and LES, and slippery is not

Romps and Oktem, GRL (2015)

Are clouds slippery or sticky?

Prologue:
The Introduction

Act I:
Stereo Photogrammetry

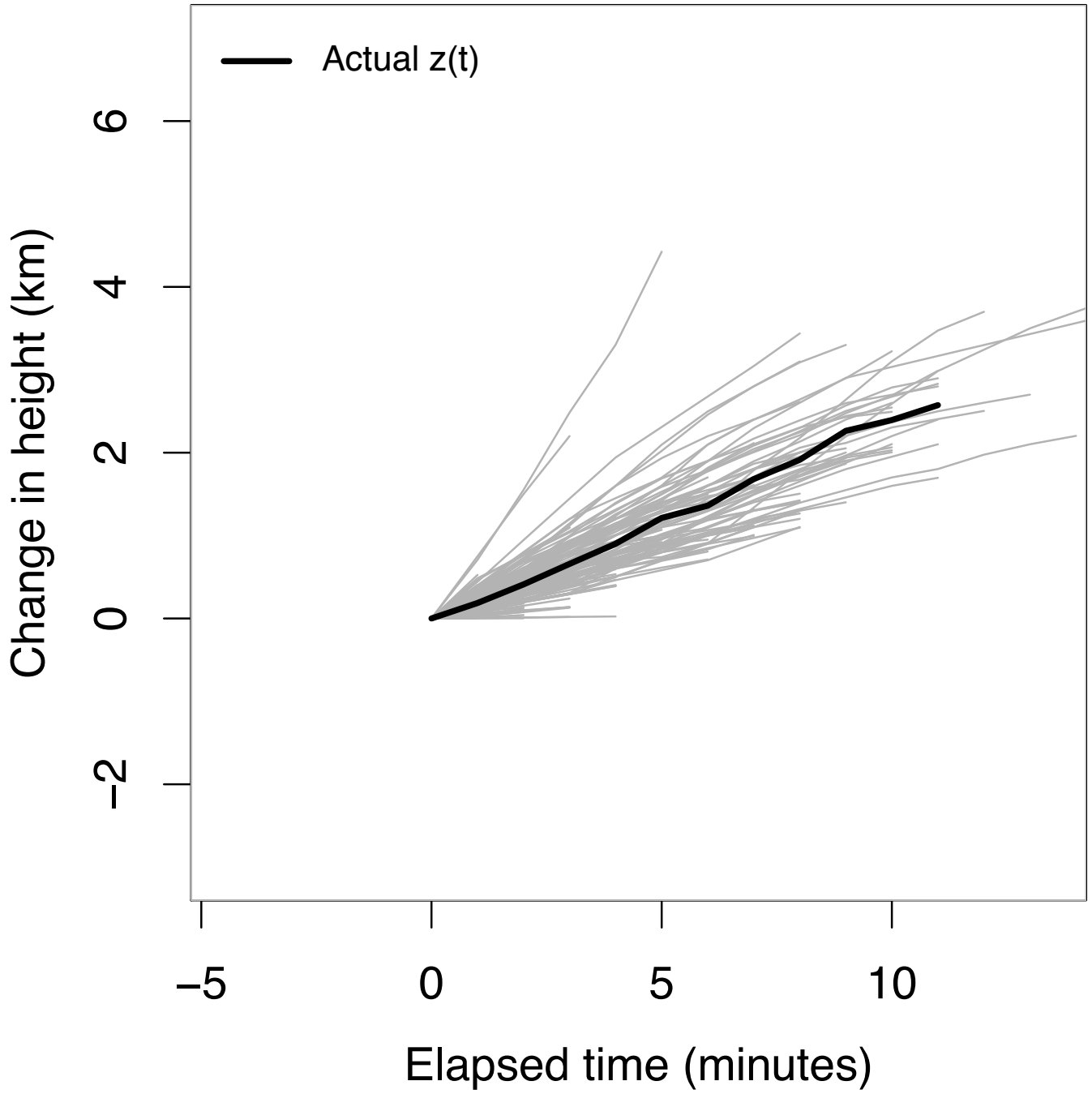
Act II:
Large-Eddy Simulations

Alex Charn

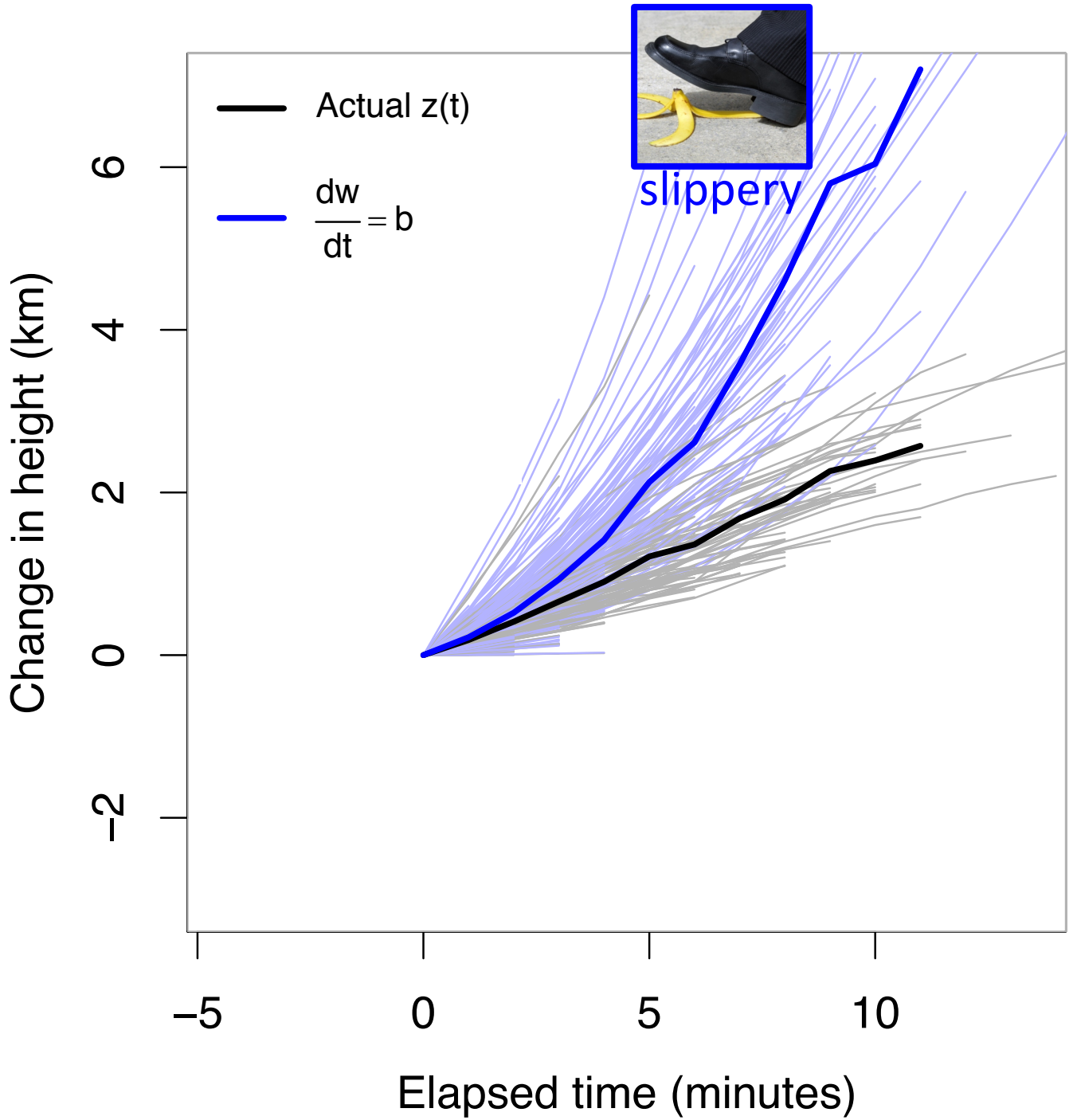
UC Berkeley

Track cloud thermals algorithmically in a large-eddy simulation

Movie credit: Jacob Seeley

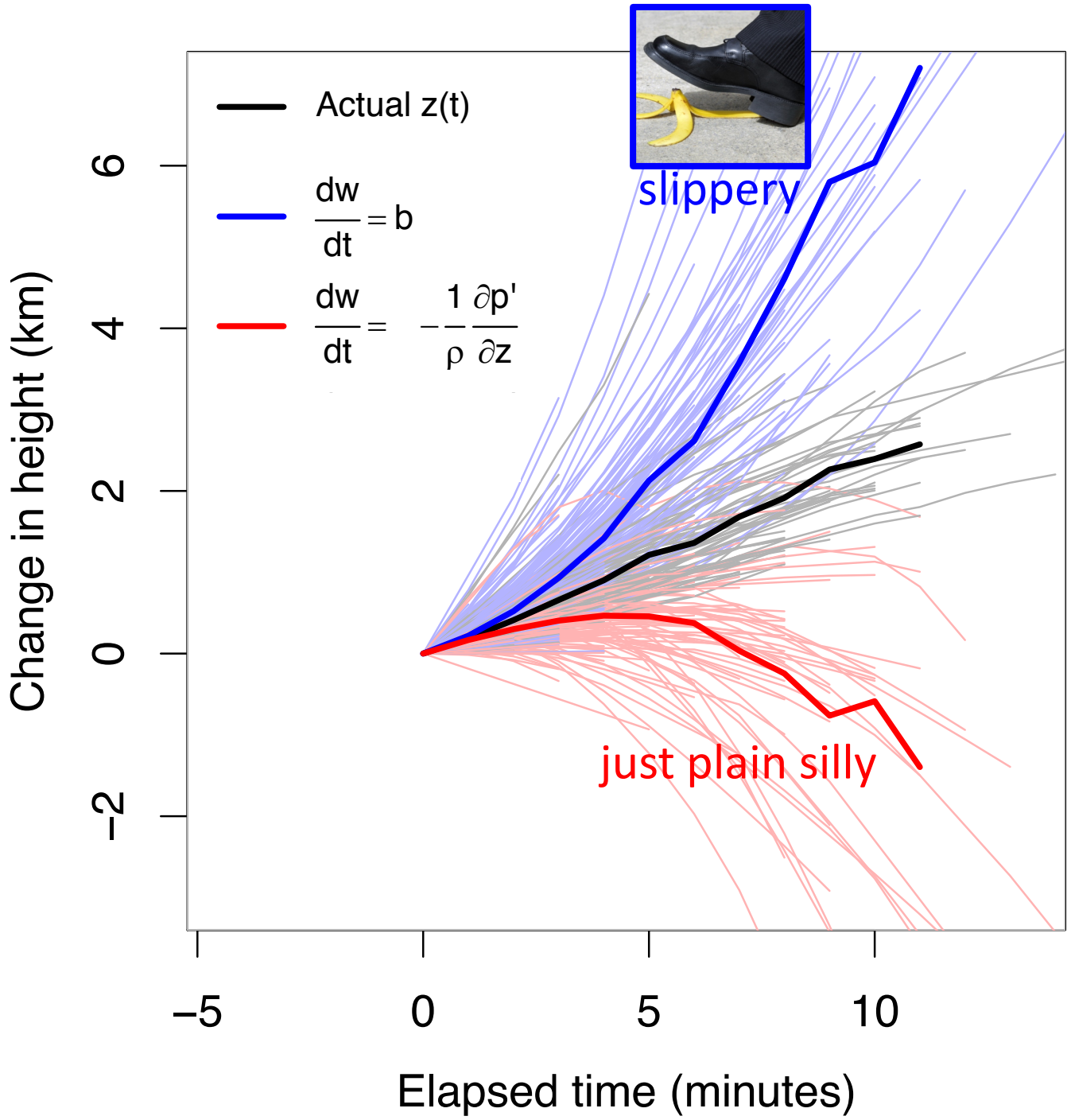


Black lines are actual cloud trajectories.



Black lines are actual cloud trajectories.

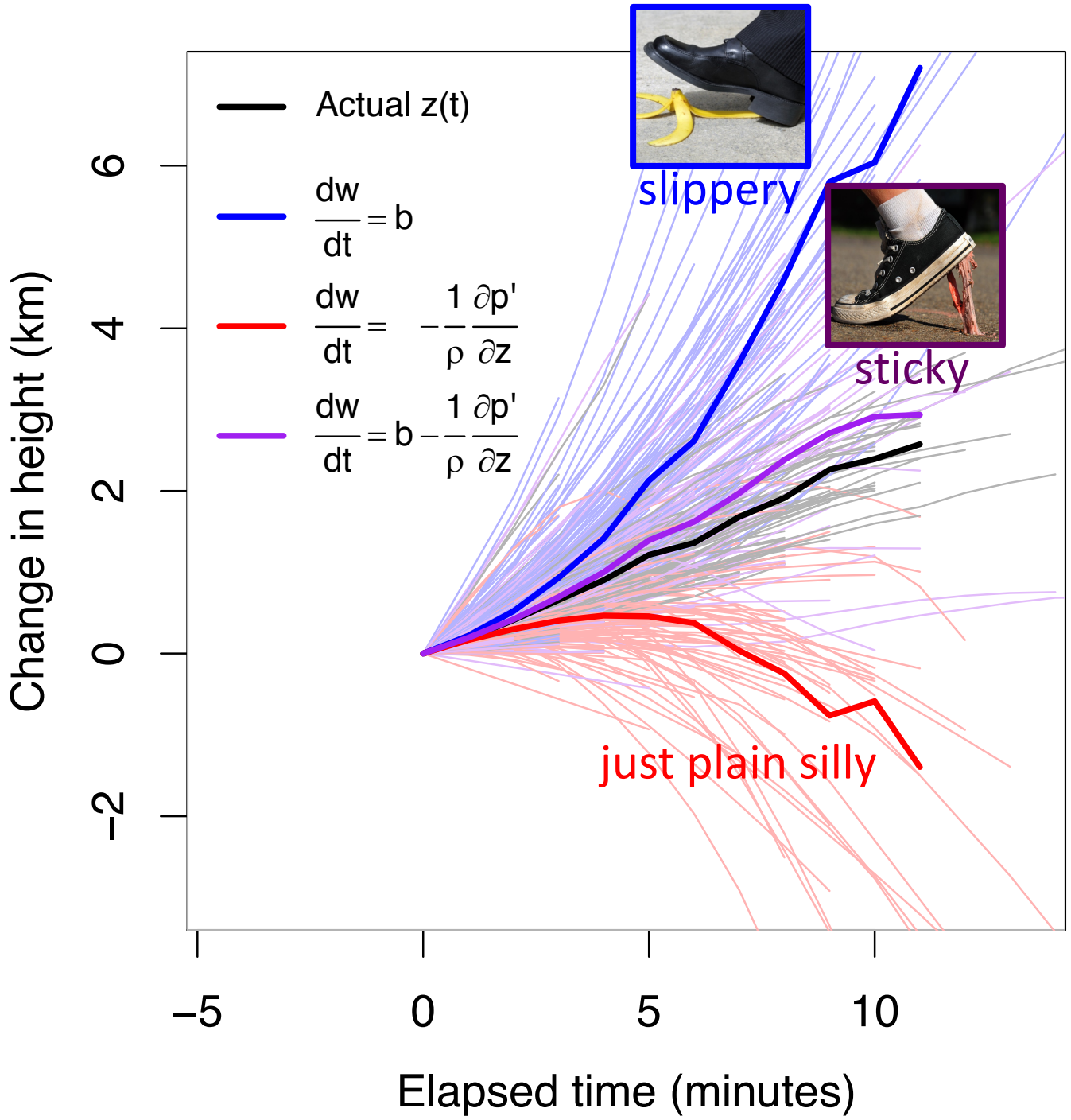
If we reconstruct z(t) using only buoyancy (slippery hypothesis), too much acceleration.



Black lines are actual cloud trajectories.

If we reconstruct z(t) using only buoyancy (slippery hypothesis), too much acceleration.

If we use only drag ("silly" hypothesis), too much deceleration.



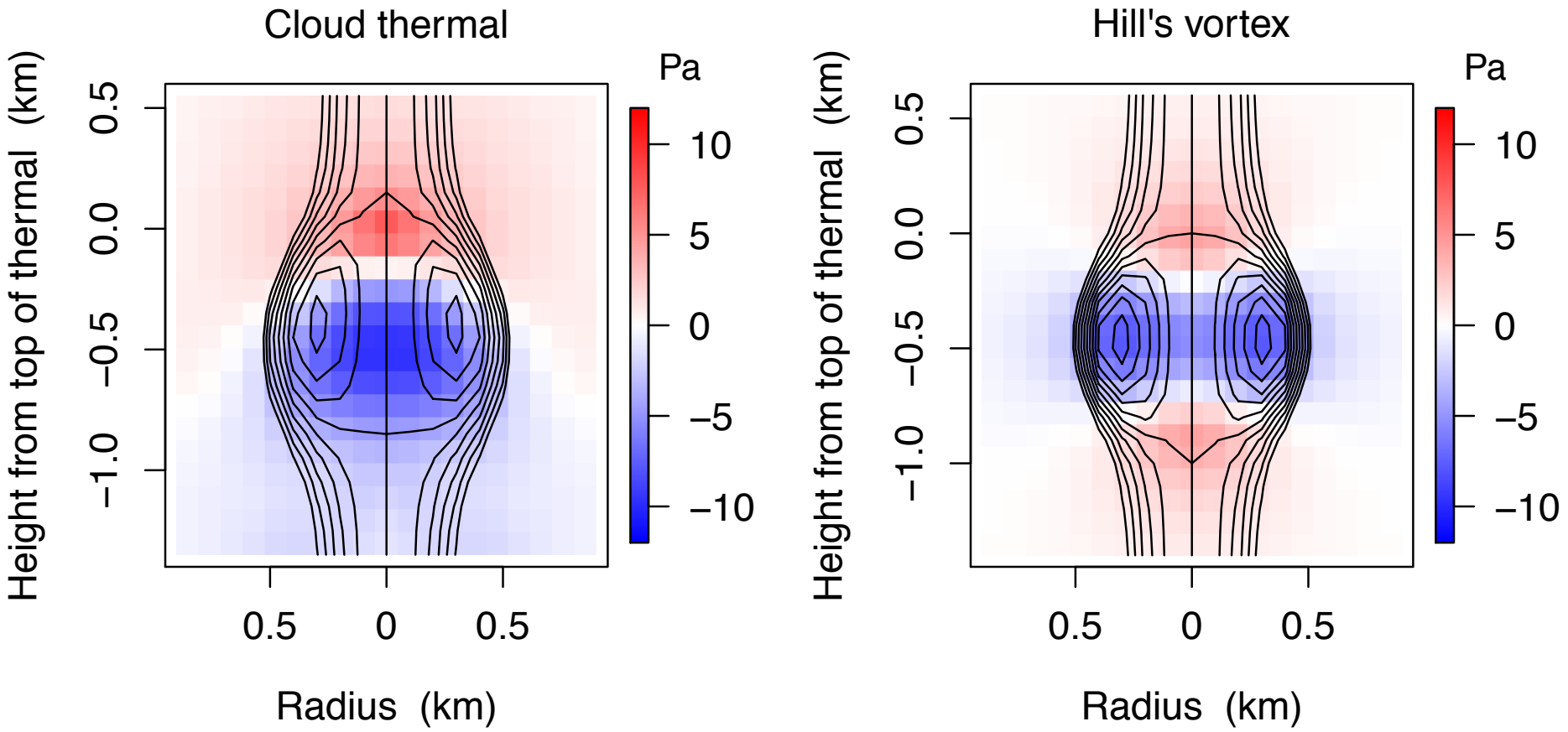
Black lines are actual cloud trajectories.

If we reconstruct z(t) using only buoyancy (slippery hypothesis), too much acceleration.

If we use only drag ("silly" hypothesis), too much deceleration.

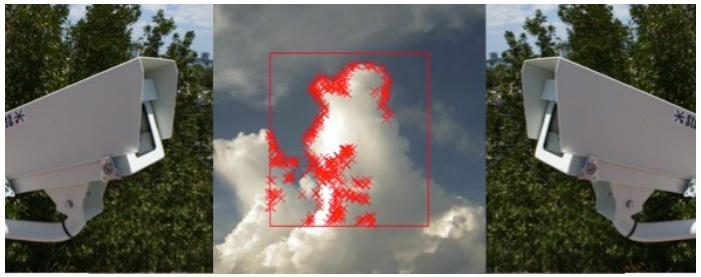
Constant rise is given by a balance between buoyancy and drag (sticky hypothesis).

Why are cloud thermals are not slippery like Hill's vortex?



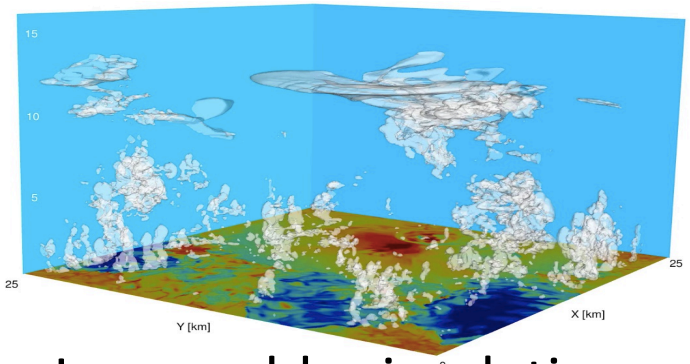
Hill's vortex is slippery thanks to its fore-aft symmetry,
a symmetry that real cloud thermals do not have.

Are clouds slippery or sticky?



Stereo photogrammetry

Sticky



Large-eddy simulation

Sticky

In other words, buoyancy is largely balanced by drag in mature cloud thermals

Outline

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3. What sets cloud cover?
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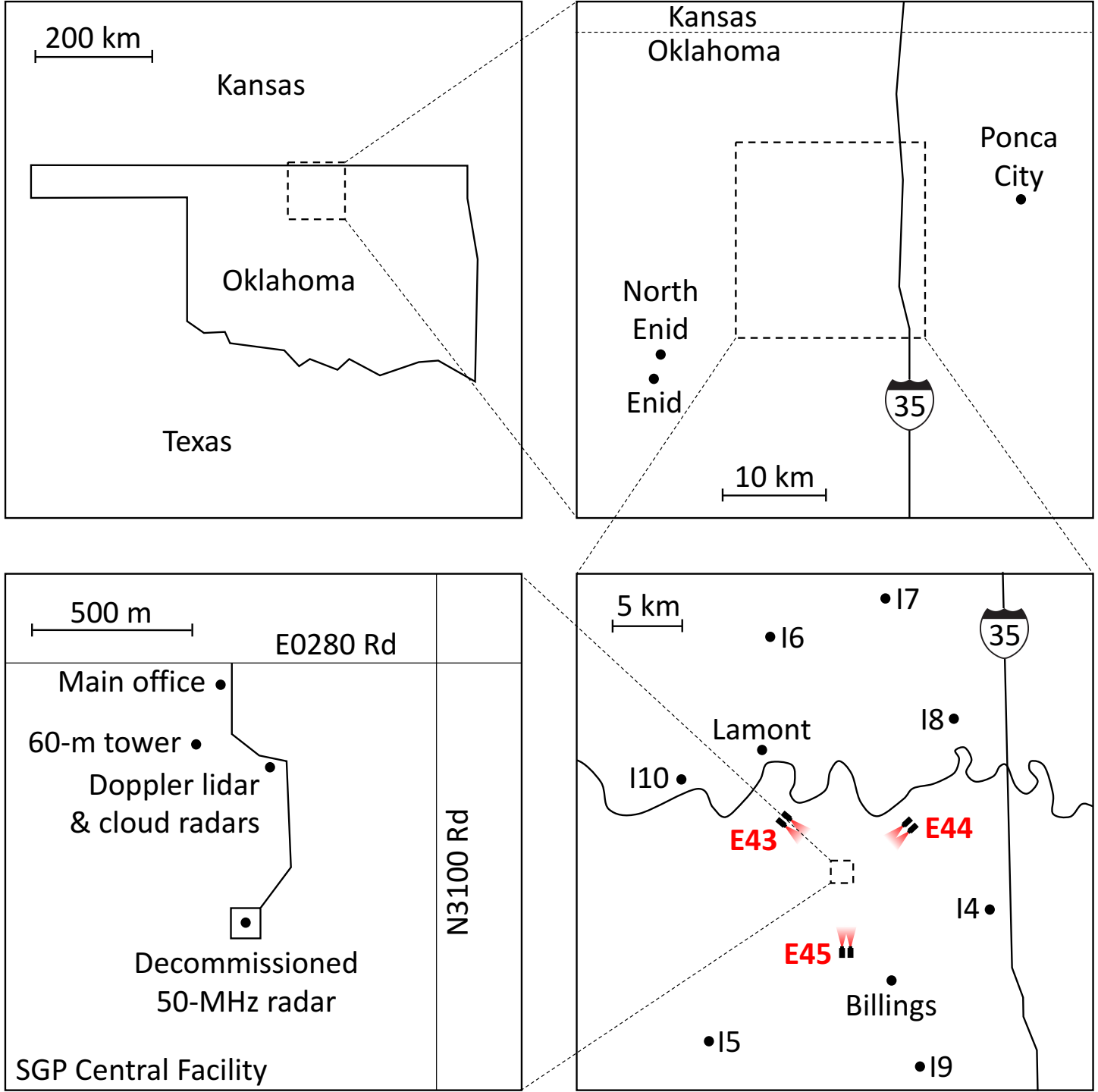
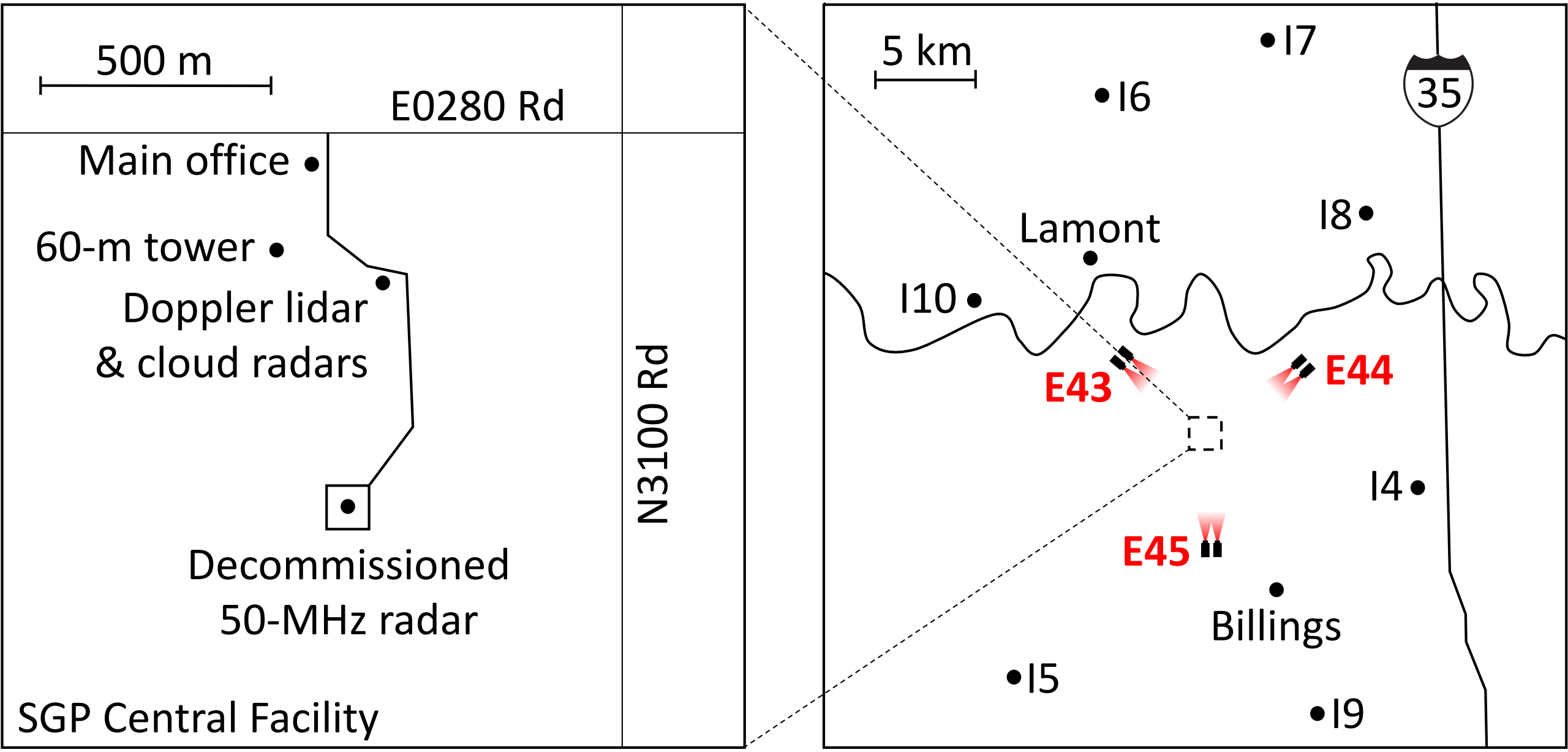
CLOUDS OPTICALLY GRIDDED BY STEREO

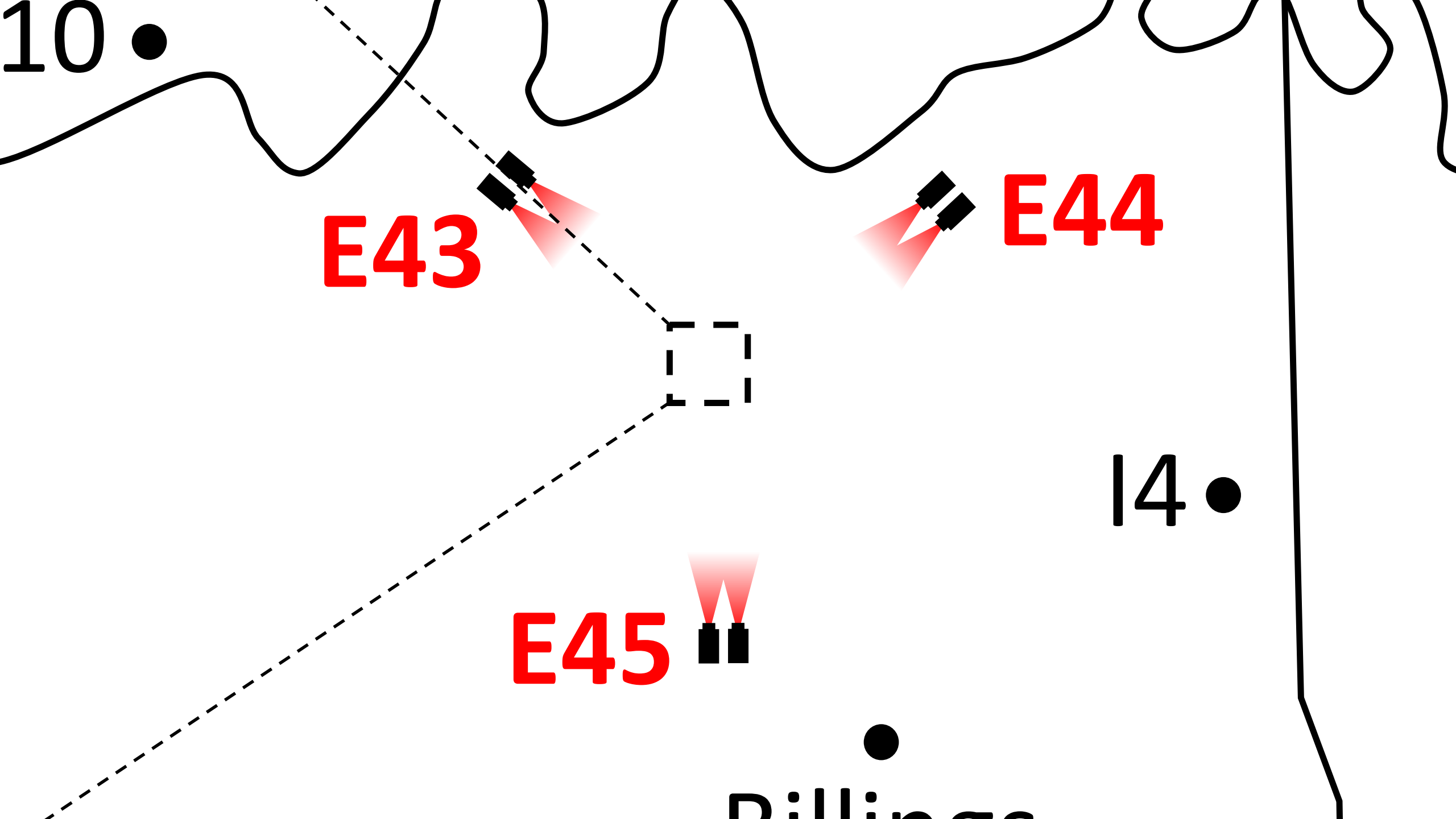
Published in the December 2018 issue of BAMS

NOT featured on the cover

But, we tried…


200 km
Kansas
Oklahoma
Texas
Kansas
Oklahoma
Ponca
City
North
Enid
Enid
35
10 km
500 m
E0280 Rd
Main office
60-m tower
Doppler lidar
& cloud radars
Decommissioned
50-MHz radar
N3100 Rd
SGP Central Facility
5 km
I7
I6
35
Lamont
I8
I10
E43
E44
I4
E45
Billings
I5
I9


500 m
E0280 Rd
Main office
60-m tower
Doppler lidar
& cloud radars
Decommissioned
50-MHz radar
N3100 Rd
SGP Central Facility
5 km
I7
I6
35
Lamont
I8
I10
E43
E44
I4
E45
Billings
I5
I9


10
E43
E44
14
E45

E43

E43a

E43b

E44

E44a

E44b

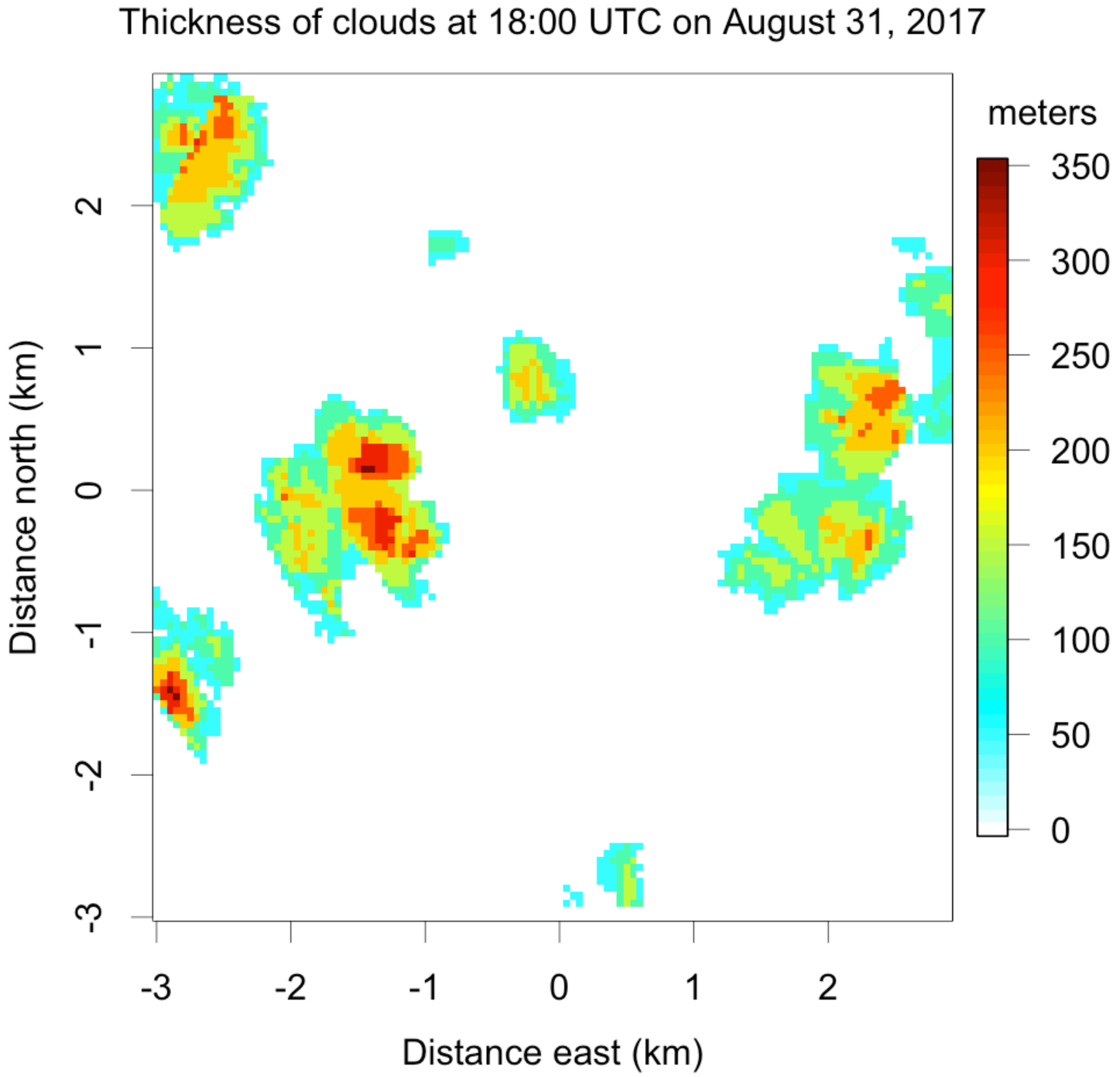
E45

E45a

E45b

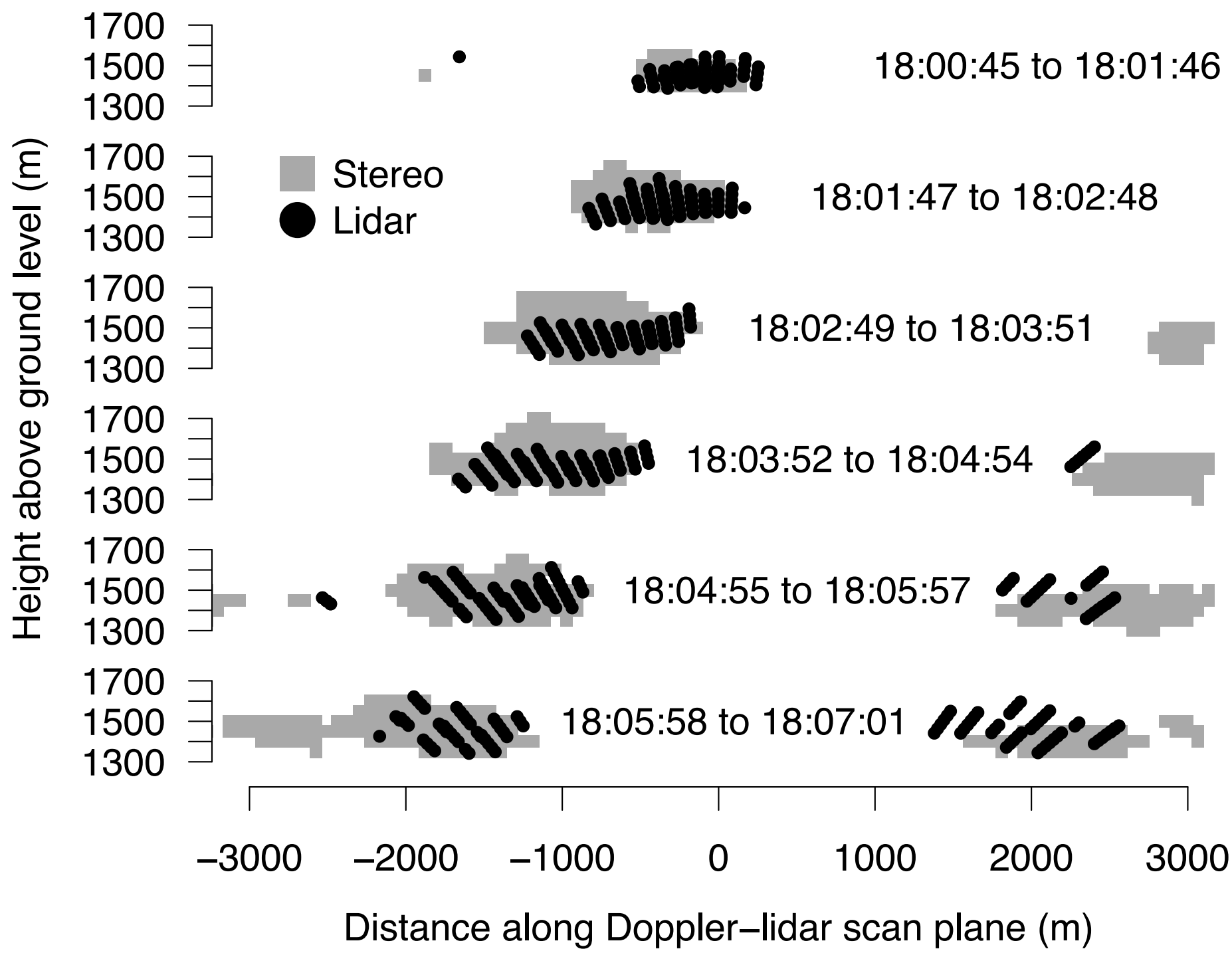
The moment the camera ring turns on.

18:00 UTC, August 31, 2017



Clouds Optically Gridded by Stereo

How accurate is COGS?



Scanning Doppler lidar (black points)

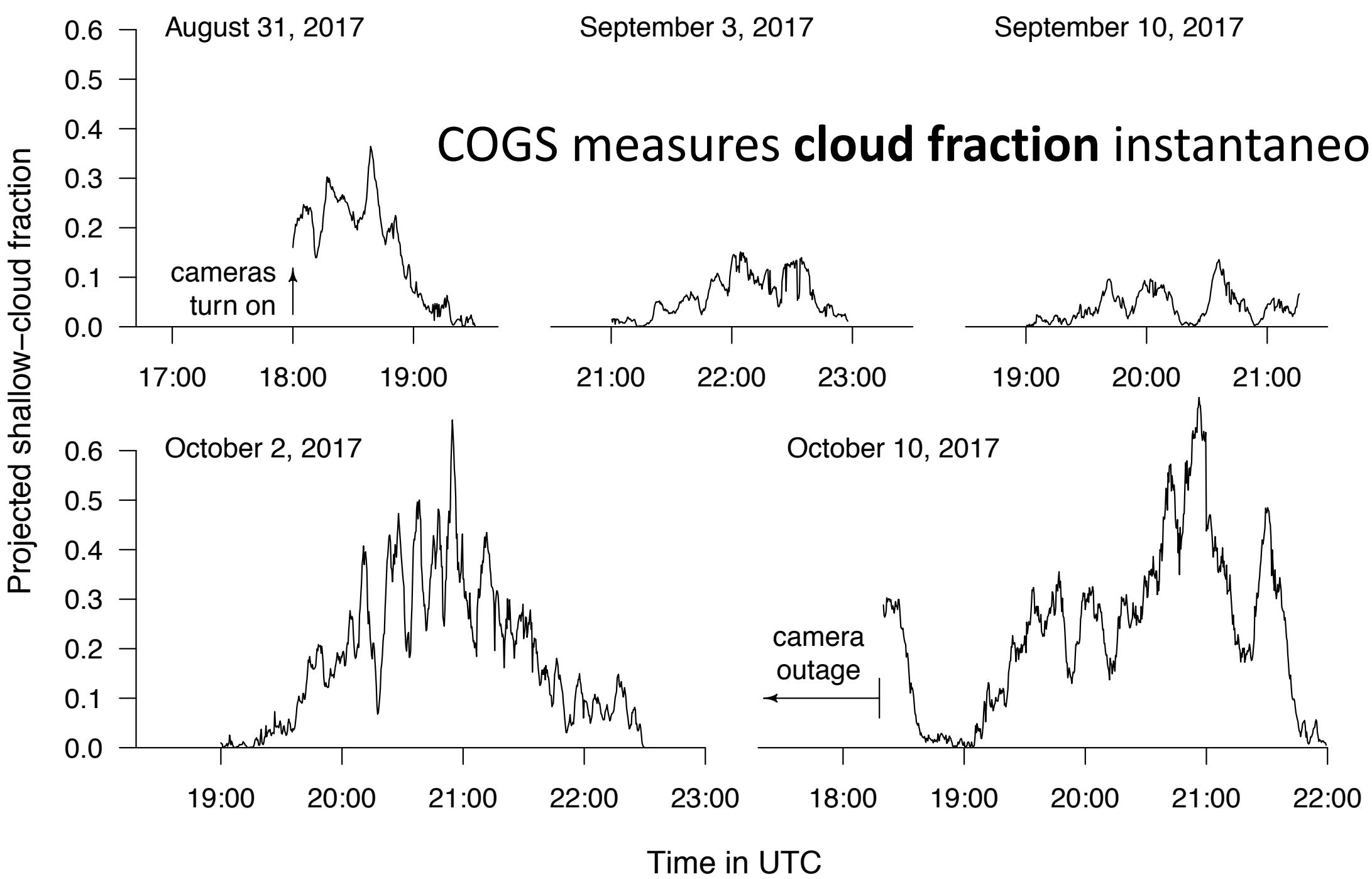
and

COGS (grey shading)

What can COGS do?

For ShCu:

Cloud fraction
Cloud-base height
Cloud-top height
Cloud velocities
Cloud sizes
Cloud life cycle
etc.


COGS measures **cloud fraction** instantaneously
August 31, 2017
September 3, 2017
September 10, 2017
October 2, 2017
October 10, 2017
Projected shallow−cloud fraction
0.0
0.1
0.2
0.3
0.4
0.5
0.6
cameras
turn on
camera
outage
17:00
18:00
19:00
21:00
22:00
23:00
19:00
20:00
21:00
19:00
20:00
21:00
22:00
23:00
18:00
19:00
20:00
21:00
22:00
Time in UTC

Outline

1. Are clouds sticky or slippery?
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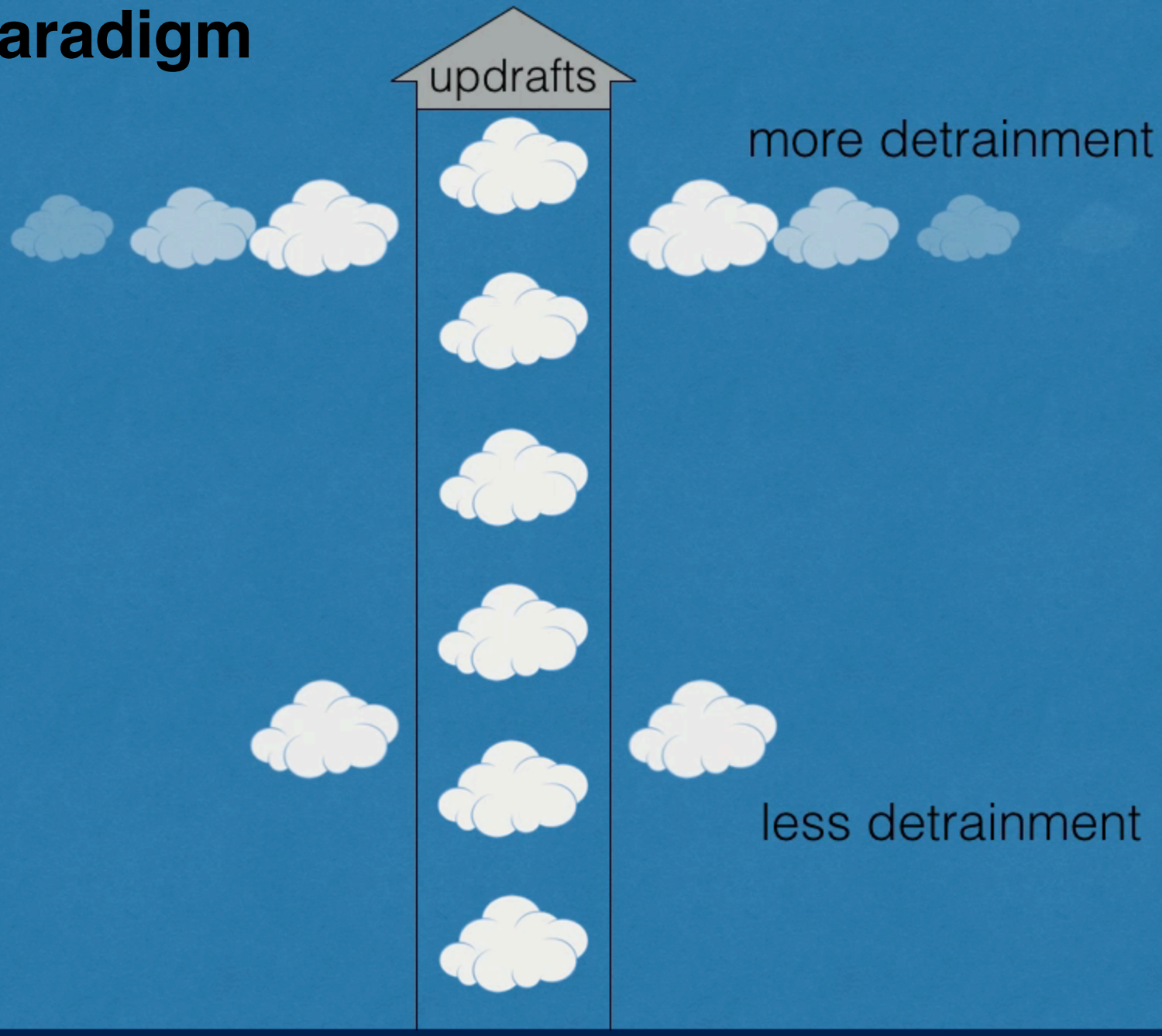
A short story about the tropical upper troposphere…

Jake Seeley

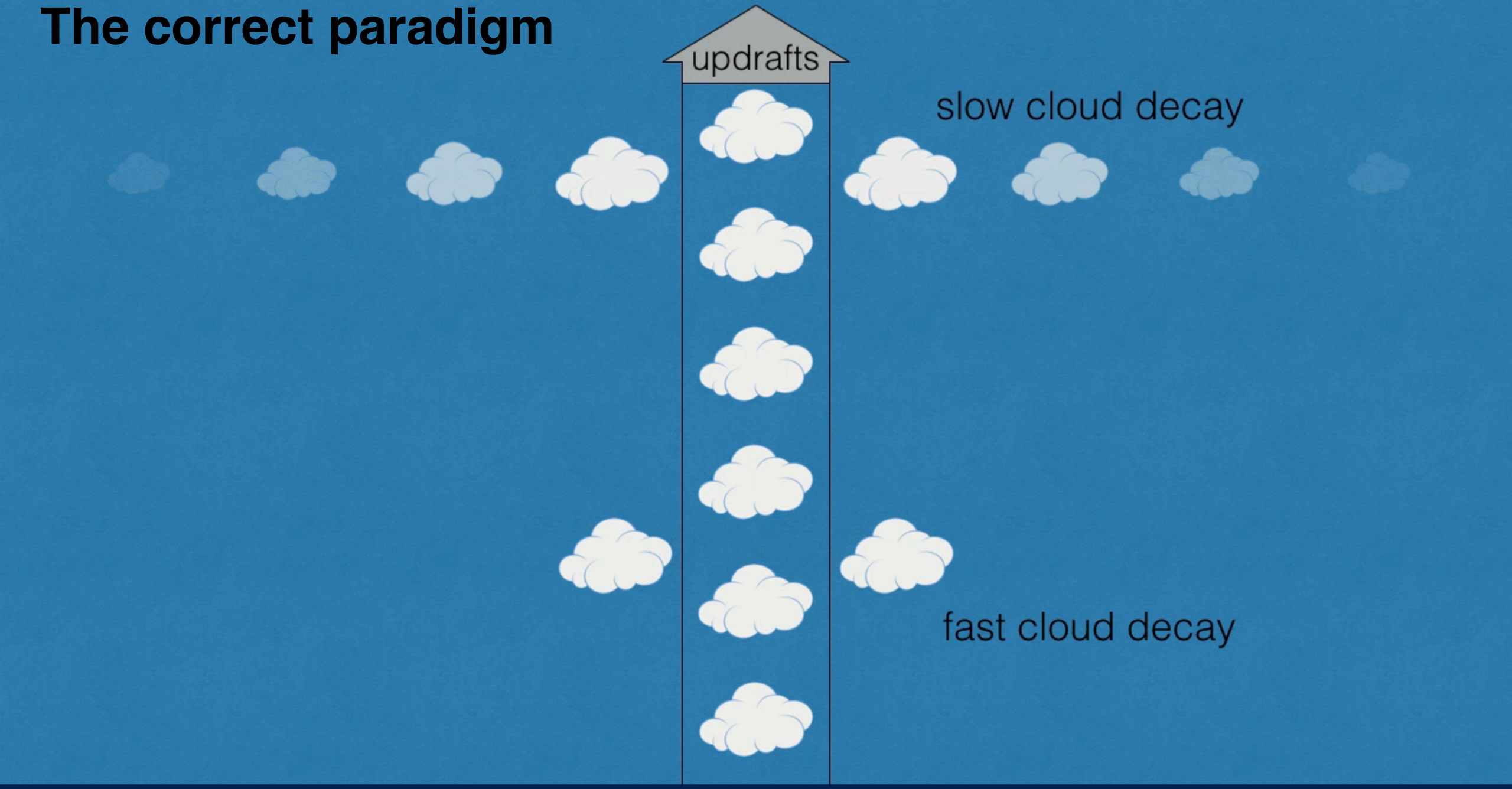
Why is there so much cloud cover in the upper troposphere?

Or, why do Cb resemble anvils?

The current paradigm

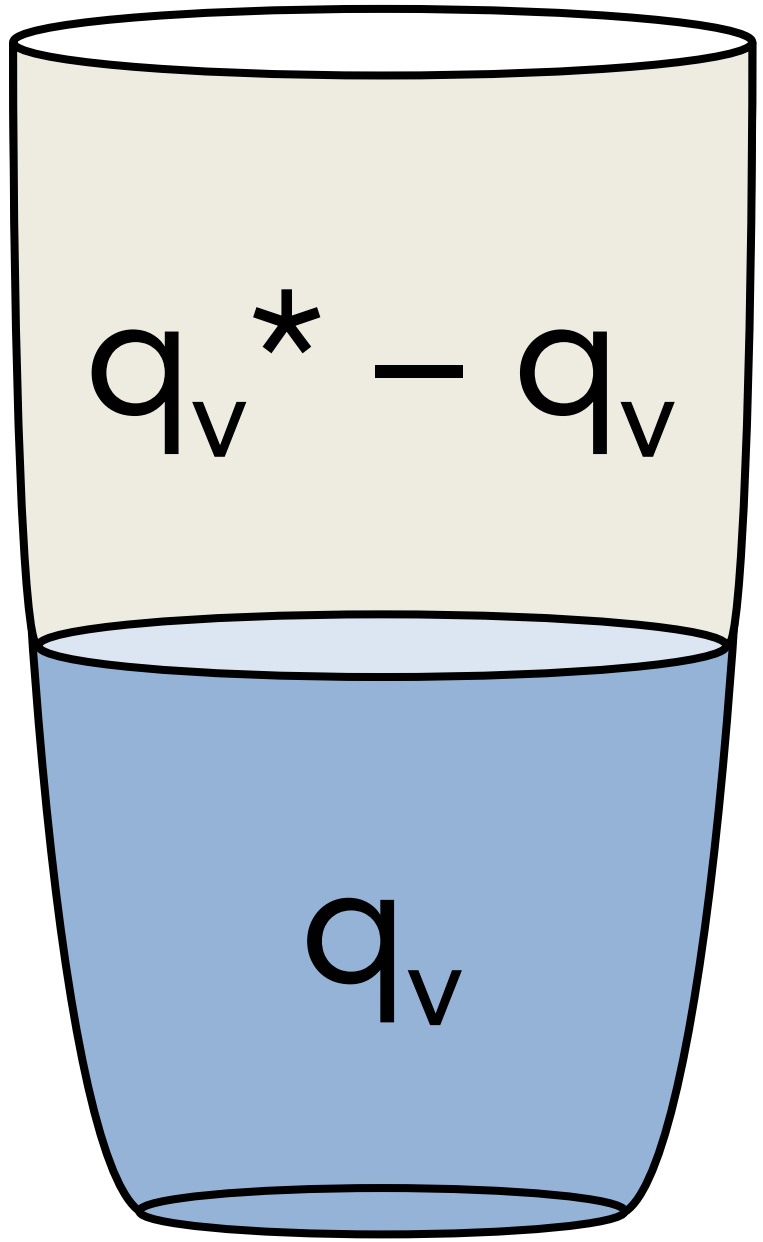


The correct paradigm



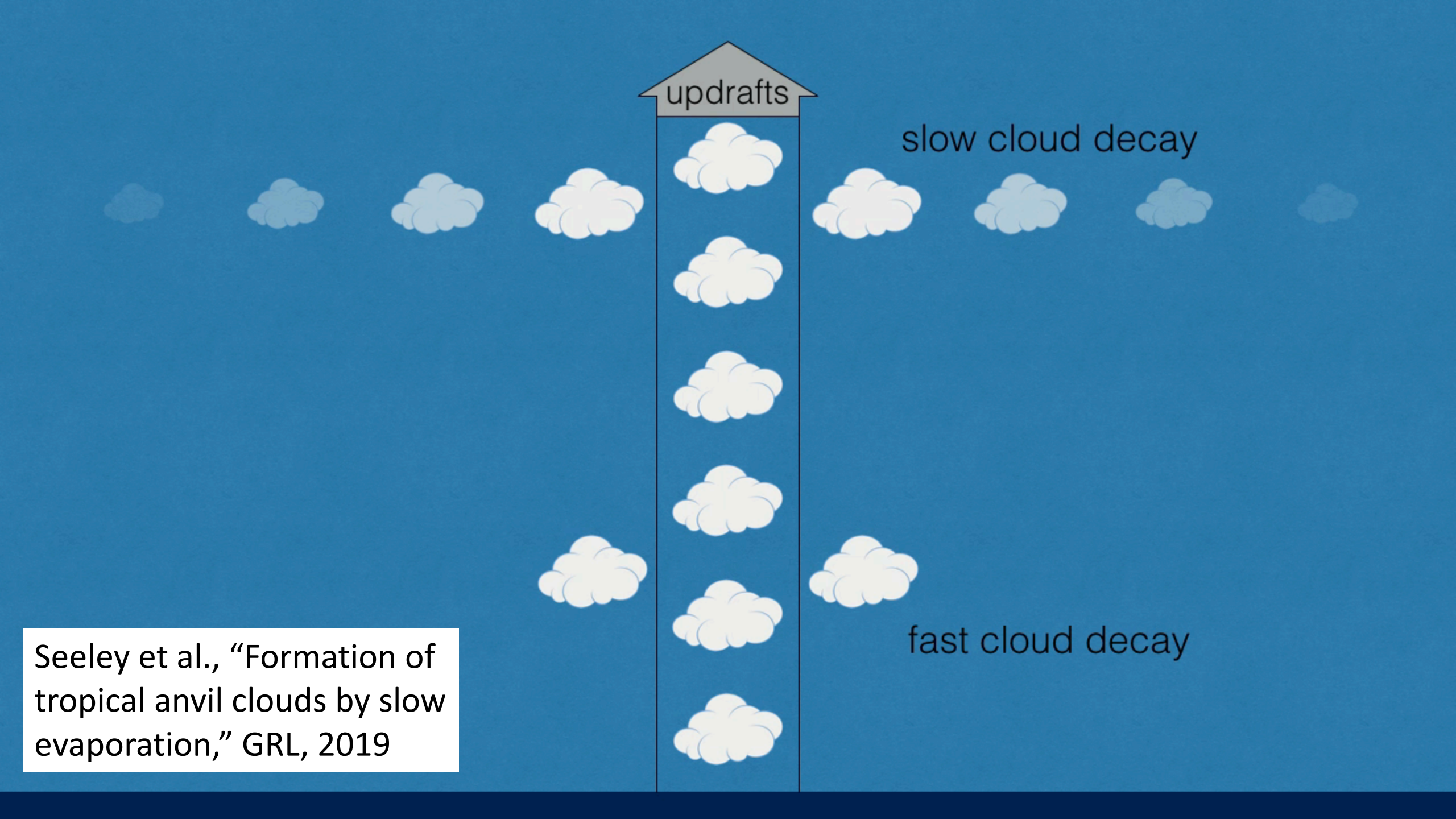
At every height in the atmosphere, there is a specific humidity, q_v

But, the interesting part is the subsaturation, $q_v^* - q_v$



Mixing causes clouds to decay.

Cold upper troposphere



Seeley et al., “Formation of tropical anvil clouds by slow evaporation,” GRL, 2019

What does this story have to do with COGS?

To point out that cloud lifetimes matter

They matter for Cb, and they matter for ShCu

And, **we can measure cloud lifetimes using COGS**

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Operational definitions of:

"active" (A) versus "forced" (F)

and

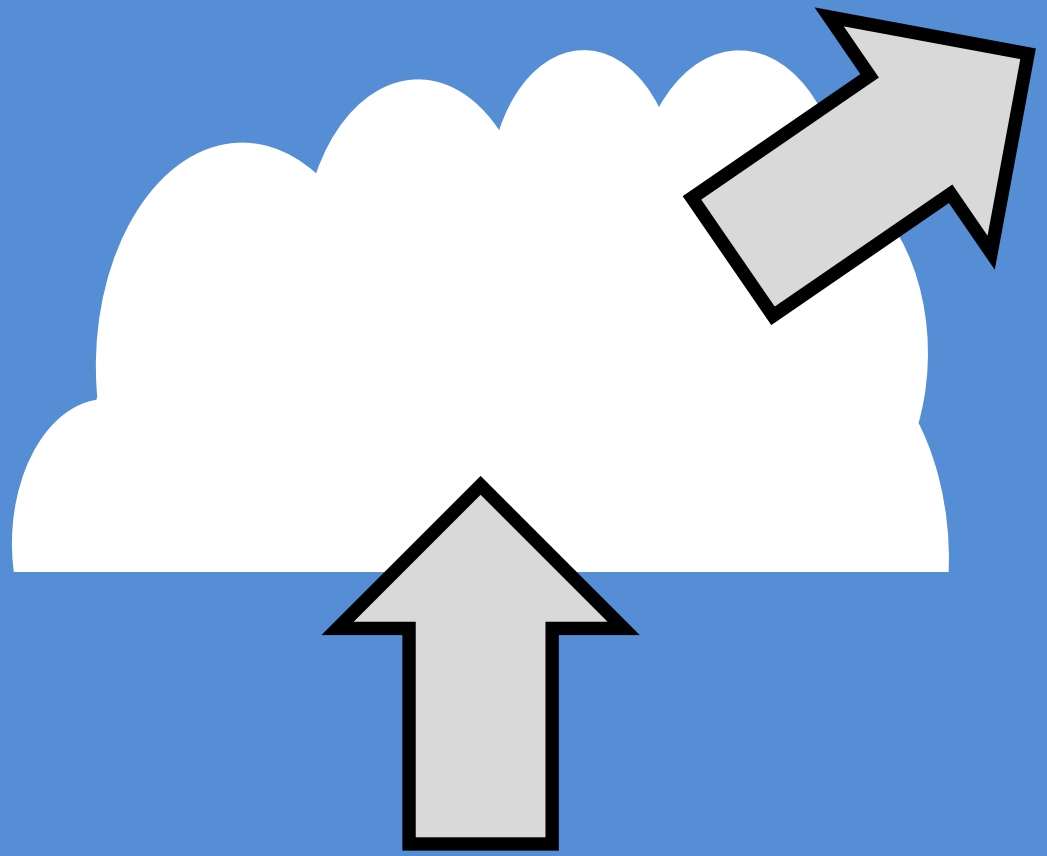
"thermal" (T) versus "plume" (P)

M_{up} = mass of air that ascends through the cloud's base
M_{down} = mass of air that descends through the cloud's base
M_{max} = maximum instantaneous mass of the cloud

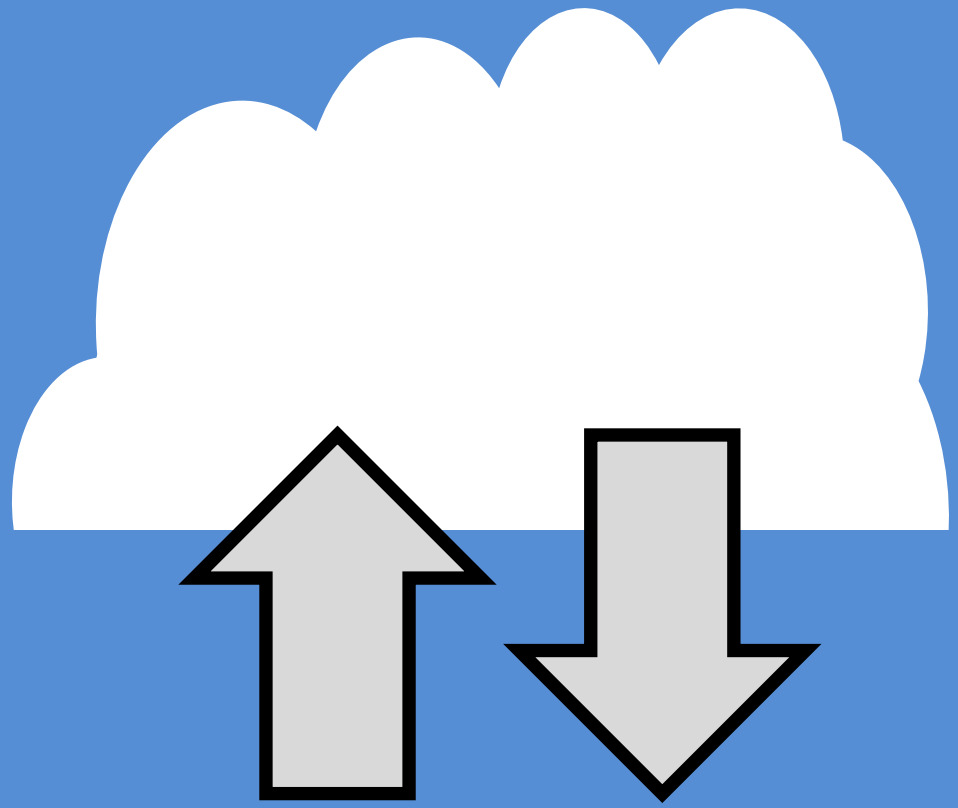
$$F = M_{down} / M_{up} = 1 - A$$

$$T = M_{max} / M_{up} = 1 - P$$

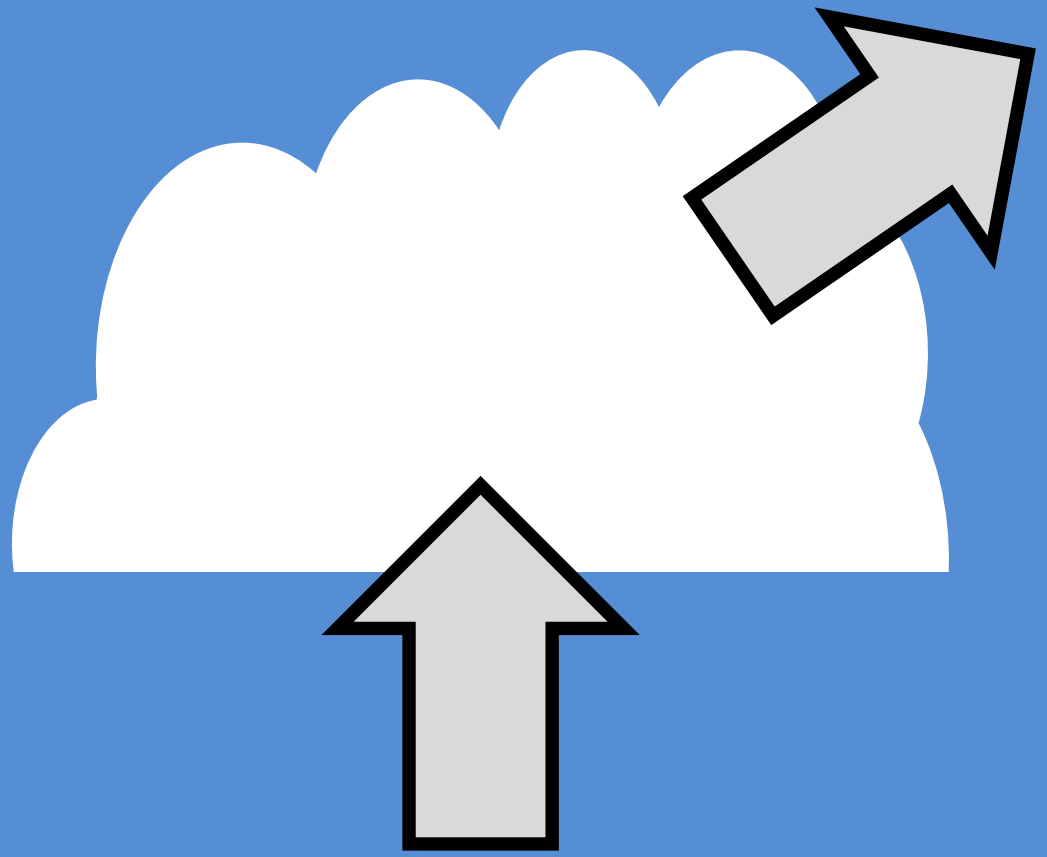
Active Thermal



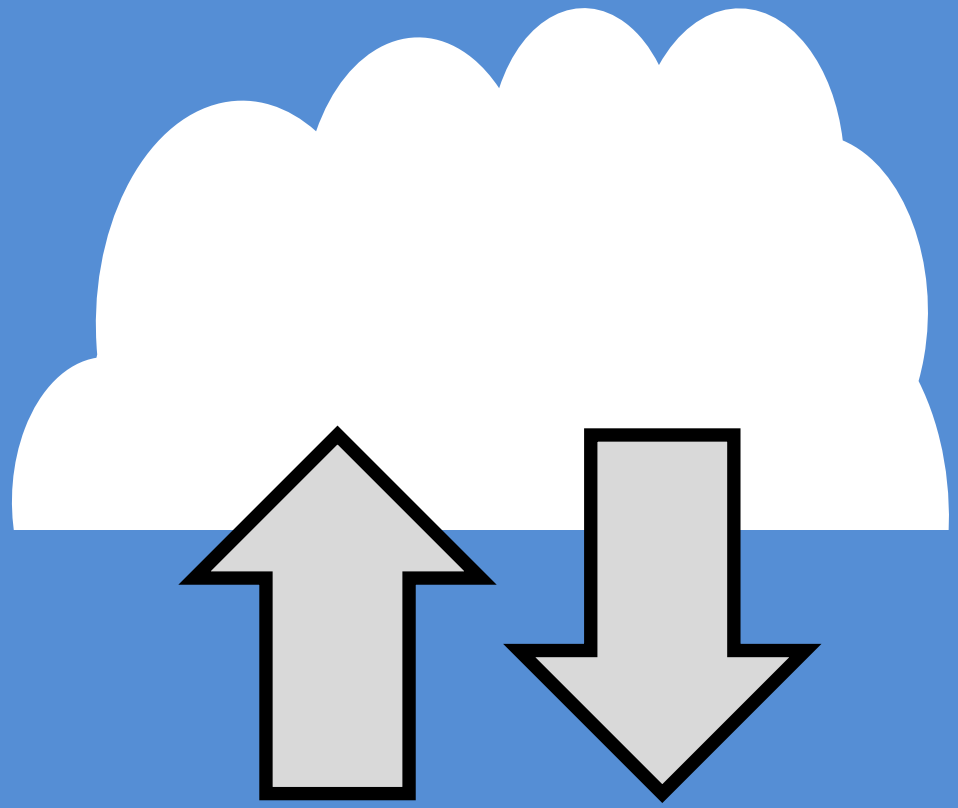
Forced Thermal



Active Plume



Forced Plume



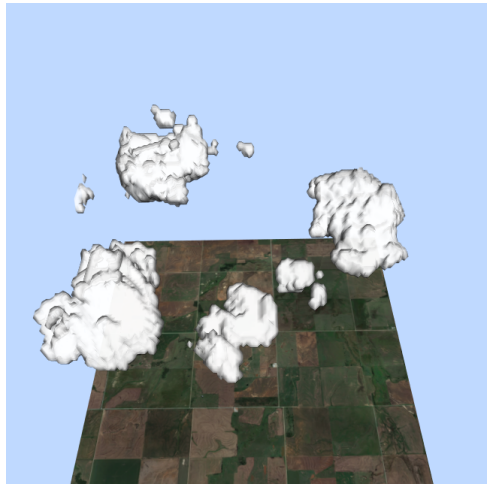
CLOUDS OPTICALLY GRIDDED BY STEREO

COGS can measure the **cloud-base area**, which is needed to calculate $\mathbf{M_{up}}$ and $\mathbf{M_{down}}$

COGS can also measure **cloud mass**, which is needed to calculate $\mathbf{M_{max}}$

1. Are clouds sticky or slippery?

2. Intro to the latest stereo product: COGS



3. What sets cloud cover?

4. Are clouds thermals or plumes?